

Unique Education & Workforce Development for NASA Engineers

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Abstract

NASA engineers are some of the world's best-educated graduates who are responsible for technically complex and highly significant scientific programs. Even though these professionals are highly proficient in traditional analytical competencies there is a unique opportunity to offer continuing education that further enhances their overall engineering skills. The NASA Academy of Program/Project & Engineering Leadership (APPEL) provides educational resources encouraging foundational learning, professional development, and knowledge sharing. NASA APPEL is currently expanding its engineering curriculum beyond mathematical analysis and traditional engineering subject matter to the areas of:

- 1) Understanding NASA's overall vision and the Agency initiatives supporting them.
- 2) Sharing NASA's reservoir of engineering experience and lessons learned.
- 3) Innovatively designing hardware for manufacturability, assembly, and servicing.

NASA APPEL strives to intellectually stimulate the Agency's technical professionals, build its capacity for future performance, and exemplify its core values—all to better enable NASA to meet its strategic vision.

NASA Engineering Education

NASA employs some of the best and brightest engineers in the world. NASA offers several career enhancing opportunities for its staff, such as facilitating enrollment in university provided master's and doctoral programs. But other educational options exist internally through the NASA Academy of Program/Project & Engineering Leadership (APPEL).

NASA APPEL is managed by the Office of the Chief Engineer at NASA Headquarters in Washington, D.C. APPEL contributes to NASA's mission by promoting individual and team excellence in program/project management and engineering.

NASA APPEL supports individual practitioners, as well as project and program teams at every level of development. It does so through three primary business lines: curriculum, knowledge sharing, and performance enhancement. Curriculum lies at the heart of NASA APPEL's approach to building the Agency's program/project and engineering capabilities. Its courses are designed using project management and systems engineering competency models, and focus on what the participants need to enhance their own capabilities, knowledge, and skills.

NASA APPEL's curriculum consists of four core courses and a wide array of in-depth courses. The core curriculum develops and enhances the essential skills and knowledge necessary to successfully perform in NASA's project environment. NASA APPEL in-depth courses are comprised of an extensive collection of project management, systems engineering, and engineering topics that provide more detailed, specialized education to augment the skills and knowledge gained through the core curriculum. This paper focuses on how, through its in-depth engineering course offerings, NASA APPEL is developing and offering unique coursework that enhances the Agency's engineering workforce.

With both a strong undergraduate analytical foundation and higher education opportunities available to NASA engineers, NASA APPEL's mission is to focus on areas in an engineer's training that may have been understated or simply lacking during their formal education. To accomplish this, NASA APPEL reviewed current engineering undergraduate degree requirements and surveyed numerous engineers and engineering managers throughout the Agency. From this data, we identified several areas in NASA's technical workforce's educational background that were regarded as weak. As a result, NASA APPEL is developing courses in three key areas:

- I. Understanding NASA's overall vision.
- II. Sharing NASA's engineering experience and lessons learned.
- III. Designing hardware for manufacturability, assembly, and servicing.

(I) A Better Understanding of What NASA Does

To satisfy this first area of engineering educational needs, it is important to understand the unique requirements related to NASA missions which are described in NASA's Vision Statement: "To understand and protect our home planet, to explore the Universe and search for life, and to inspire the next generation of explorers...as only NASA can." In the development of its engineering courses, NASA APPEL is able to meet the needs of its workforce along with developing three courses that closely support the Agency's vision statement.

NASA APPEL "Earth, Moon, and Mars (EMM)" course: "To understand and protect our home planet..."

Most engineering majors in academia are not required to take a course in geology. At NASA, engineers are tasked with exploring our own planet, the Moon, and Earth's neighboring planet, Mars. It is crucial that the engineers who are designing the hardware to accomplish these complex, technical challenges understand how our planet works and also what to expect when the spacecrafts they design and build actually land on the Lunar or Martian surfaces. In order to prepare these engineers NASA APPEL has developed the *Earth, Moon, and Mars (EMM)* course that explains the formation of the Universe, our solar system, and our planet.

The goal of the EMM course is to reveal how planetary bodies are formed and the kinds of geologic processes that continue to operate on them today. Participants also learn about the unique geologic properties and the challenges that the Moon and Mars pose to future exploration.

Learning methods include interactive lectures and small-group discussions. The course begins with a study of how the Earth "works." It shows how processes such as tectonic formation and erosion continue to shape the Earth's surface. Participants learn about the structure, dynamics, and composition of the Moon and Mars.

The *Earth, Moon, and Mars* course is taught by Dr. Michael Wyession, Associate Professor of Earth and Planetary Sciences, Washington University in St. Louis.

NASA APPEL "Essentials of Astronomy for Engineers" course: "...to explore the Universe and search for life..."

Most engineers have a specific, well-defined market or industry in which they work and their product designs focus on well-known, understood attributes of that market. To a NASA engineer their "industry" or "market" is the Universe. Therefore, it is important for every NASA engineer to possess a fundamental understanding of astronomy. NASA APPEL believes it is not only critical to illustrate and explain the universe to its engineers so they can more fully appreciate the scope and rationale of the work they are involved in, but also important to impart a deeper appreciation for the majesty of the universe they are tasked to explore.

The goal of the *Essentials of Astronomy for Engineers* course is to foster a physical and philosophical understanding of our universe—and incite an interest in learning more.

Main course topics include a brief history of astronomy; observing our solar system and beyond; the physics of astronomy; our solar systems' planets, stars, galaxies, and other astronomical bodies; the origin, current state, and future evolution of our solar system; an overview of Space-Time including cosmology and the Big Bang; life as we know it and search for other life; and recommended resources for the astronomy hobbyist.

The *Essentials of Astronomy for NASA Engineers* course is taught by Dr. Chris Impey, University Distinguished Professor and Deputy Head of the Astronomy Department, University of Arizona in Tucson.

NASA APPEL "NASA Missions: Engineering Exploration" course: "...to inspire the next generation of explorers...as only NASA can."

NASA is involved in a wide variety of scientific research, development, and operational programs in both aerospace and aeronautics. In order to allow a workforce that is spread across the country to understand and appreciate the entire scope of NASA's work and the

benefits it has brought, the *NASA Missions: Engineering Exploration* course was developed. NASA is tasked numerous technical challenges and it is important that all NASA employees are not only aware of, but also informed about the accomplishments of their Agency.

Learners will recognize how the driving forces behind Agency-wide successes are more than science and analytics, and how innovation, teamwork, and passion are also crucial components of an engineer's daily work. The goal is for attendees to apply this to their own daily thinking.

The course will include synopses of major NASA human spaceflight missions; major NASA robotic missions; overview and possible timelines of future NASA missions and technical challenges; importance of America's space program; conclusions in support of NASA's current programs and future vision; and recommended resources for continued learning.

The *NASA Missions: Engineering Exploration* course is taught by Andrew Chaikin, science journalist, author, speaker on space exploration.

(II) Engineering Experience and Lessons Learned

For more than fifty years, NASA has had countless successes along with several tragedies and missteps. Relying heavily upon the lessons gained from over half a century of experience, NASA APPEL has developed two courses that help less experienced engineers gain valuable lessons from both NASA successes and mistakes. Using an extensive catalog of official case studies, NASA APPEL is able to convey key lessons learned and engineering lessons to a whole new generation.

NASA APPEL "Seven Axioms of Good Engineering (SAGE)" course:

NASA has learned tragically from its own past that engineering accomplishments require more than good technical skills. They require a strong dose of engineering wisdom, as well. Such wisdom is gained by appreciating historical achievements and understanding past mistakes. As the Scottish author, Samuel Smiles once wrote: "We learn wisdom from failure much more than from success. We often discover what will do, by finding out what will not do; and probably he who never made a mistake never made a discovery."¹

The *Seven Axioms of Good Engineering* course takes a reflective look at numerous case studies, both from within NASA and the outside world, to discover where the root causes of most failures reside. Through the investigation of various examples, the attendees lead themselves to the discovery and application of axioms that bring a non-technical, yet crucial, sense of wisdom to the design process. These seven are: 1) avoiding a selective use of historical design data; 2) extrapolating existing data into unknown regions of the

design space only with extreme caution; 3) understanding the design's sensitivity and robustness; 4) always testing against physicality; 5) guarding against unanticipated loads and/or failure modes; 6) avoiding highly coupled system unless a strong benefit is shown; and 7) ensuring human understanding of how the system works.

The purpose of SAGE is to demonstrate good engineering design and project management through case studies and discussions. SAGE helps promote critical thinking, and helps improve decision making among NASA engineers, technologists, program managers, and scientists.

The course is primarily taught using a case study format. Participants are given the opportunity to create their own design corollaries and case studies based upon their own experiences, and then present their cases incorporating the engineering axioms learned.

The *Seven Axioms of Good Engineering* is taught by Dr. Tony Luscher, Associate Professor, Department of Mechanical Engineering, at the Ohio State University.

NASA APPEL “Space Systems Development: Lessons Learned (SSD)” course:

The goal of the SSD course is to examine the root causes of aerospace-specific mishaps and the applicable lessons that can be derived from these historical incidents. The majority of space mishaps studied in SSD are technical problems that can be traced to easily recognizable and preventable engineering causes. Many never-before-seen archival photographs and videos are included in the presentation, along with meaningful personal anecdotes.

The *Space Systems Development: Lessons Learned* course is taught by Larry Ross, CEO of Aerospace Engineering Associates and former Director of NASA Lewis Research Center (now NASA Glenn Research Center) and Joe Nieberding, President of Aerospace Engineering Associates and former NASA Lewis Research Center Advanced Space Analysis Division Chief.

(III) Designing Hardware for Manufacturability, Assembly, and Servicing

By nature, engineers tend to be conservative. This is a necessary trait, especially in the aerospace community, where human lives and/or hardware worth billions of dollars are typically at stake in an engineer's design. Unfortunately, there are many times when this tendency overshadows an engineer's creativity. NASA APPEL's third area of engineering education supports the Agency's understanding that engineers need the freedom and inspiration to develop inventive, creative aspects within their discipline, but still do so in a crucial manner that does not increase risk and cost.

In addition, innovative design and creativity must be communicated effectively to the technicians who will manufacture and assemble the hardware. Too often there has been a disconnect between both of these critical stakeholders. Technicians possess years of valuable practical experience working with hardware that most engineers lack. NASA has seen the value of collaborating and sharing this knowledge via concurrent engineering.

NASA APPEL “Innovative Design and Engineering Applications (IDEAs)” course:

The key to product design and engineering success is to be able to think creatively. This is especially true for NASA engineers who must develop complex hardware that withstands the harshest of environments while generating critical data and mission successes for the space program.

The goal of this course is to make analytically minded engineers feel comfortable thinking differently. This is accomplished through the introduction of several established problem-solving techniques used in other industries (such as the Pugh or TRIZ methods), and also by undertaking team projects in class where attendees must design a product with very limited resources.

The learning methods employed in the IDEAs course include an integrated case study comparing the Wright Flyer of 1903 to the Apollo Lunar Lander, which demonstrate the visualization of multi-disciplinary teamwork during the early stages of design.

The *Innovative Design and Engineering Applications* course is taught by Mr. John Sturrock, Director of Strategic Development for Celerant Consulting.

NASA APPEL “Design for Manufacturability and Assembly (DMA)” course:

Perhaps one of the biggest changes that has taken place in the typical academic engineering program is the de-emphasis of drafting skills and manufacturing training. Prior to the World War II era, many engineers were former machinists who understood the products they fabricated so thoroughly that they were promoted to engineers. Today, this natural progression has migrated in the other direction, as all engineers must be degreed yet, too often, they lack the practical real- world knowledge and experience gained in the machine shop.

The *Design for Manufacturability and Assembly* course was developed with the input of engineers and craftsmen throughout the Agency. It shares the “secrets of the trade” that facilitate manufacturing and assembly, along with an eye towards the inevitable need for future maintenance, servicing, and sustainability.

The goal for DMA is to provide students with the skills and insight necessary to design mechanisms, devices, and structural components that are produced quickly, of high quality, and cost effective.

The *Design for Manufacturability and Assembly* course is co-taught by Dr. Tony Luscher, Associate Professor, Department of Mechanical Engineering, the Ohio State University and Mr. Richard Cournoyer, the group supervisor of the NASA Jet Propulsion Lab's (JPL) Prototype and R&D Machining Services.

Conclusion

NASA APPEL has developed these unique engineering courses and continues to add more to its curriculum by gathering input from internal NASA customers, academia, and industry. Overall, the NASA APPEL coursework offers unique professional development opportunities that enable participants to become and remain outstanding engineers.

While no formal testing is currently done after attending these engineering courses, feedback surveys are completed by every student for course improvement. Various factors assessed include: what was learned that will be most valuable to current job responsibilities; what teaching methods contributed most effectively to learning; overall course content ratings; and instructor appraisal. When benchmarked against the entire APPEL catalogue, high marks are typical. All of NASA APPEL's engineering courses are currently being reviewed for American Council on Education (ACE) accreditation.

Author Information

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References

[1] Smiles, S., *Self-Help*, 1859.